Lynx: A high-resolution synthetic aperture radar

S. I. Tsunoda, F. Pace, J. Stence, M. Woodring

General Atomics
PO Box 85608, San Diego, CA, 92121-5608

W. H. Hensley, A. W. Doerry, B. C. Walker

Sandia National Laboratories
PO Box 5800, MS 0529, Albuquerque, NM, 87185-0529

ABSTRACT

Lynx is a high resolution, synthetic aperture radar (SAR) that has been designed and built by Sandia National Laboratories in collaboration with General Atomics (GA). Although Lynx may be operated on a wide variety of manned and unmanned platforms, it is primarily intended to be fielded on unmanned aerial vehicles. In particular, it may be operated on the Predator, I-GNAT, or Prowler II platforms manufactured by GA Aeronautical Systems, Inc.

The Lynx production weight is less than 120 lb. and has a slant range of 30 km (in 4 mm/hr rain). It has operator selectable resolution and is capable of 0.1 m resolution in spotlight mode and 0.3 m resolution in stripmap mode. In ground moving target indicator mode, the minimum detectable velocity is 6 knots with a minimum target cross-section of 10 dBsm. In coherent change detection mode, Lynx makes registered, complex image comparisons either of 0.1 m resolution (minimum) spotlight images or of 0.3 m resolution (minimum) strip images. The Lynx user interface features a view manager that allows it to pan and zoom like a video camera.

Lynx was developed under corporate funding from GA and will be manufactured by GA for both military and commercial applications. The Lynx system architecture will be presented and some of its unique features will be described. Imagery at the finest resolutions in both spotlight and strip modes have been obtained and will also be presented.

Keywords: Synthetic Aperture Radar, SAR, Remote Sensing, UAV, MTI, GMTI, CCD

1. INTRODUCTION

Lynx is a state of the art, high resolution synthetic aperture radar (SAR). Lynx was designed and built by Sandia National Laboratories and incorporates General Atomics' design requirements to address a wide variety of manned and unmanned missions. It may be operated on the Predator, I-GNAT, or Prowler II platforms which are manufactured by General Atomics (GA). It may also be operated on manned platforms. Lynx was developed entirely on GA corporate funds. GA is presently beginning the manufacture of Lynx and intends to sell Lynx units and Lynx services to military and commercial customers

Lynx is a multimode radar. Its SAR modes include a spotlight mode and two stripmap or search modes. In addition, Lynx has a ground moving target indicator (GMTI) mode. Lynx also features a coherent change detection (CCD) mode which can indicate minute changes in two SAR images taken at different times. CCD may be performed with either spotlight or stripmap images. Lynx also features a uniquely flexible user interface. The user interface features a view manager that allows Lynx to pan and zoom like a video camera. Lynx also features a conventional waterfall display for stripmap display.

Lynx operates at Ku band and is capable of 0.1 m resolution in spotlight mode and 0.3 m resolution in stripmap mode. It has a slant range of 30 km in weather and weighs less than 125 lb.

Figure 1. GA Aeronautical Systems, Inc. I-GNAT UAV

2. SYSTEM DESIGN

The Lynx SAR was designed for operation on a wide variety of manned and unmanned aircraft. In particular, it can be operated from the Predator, I-GNAT, and Prowler II platforms manufactured by GA. During System Integration testing it was operated on board Sandia's DOE DeHavilland DH-6 Twin-Otter aircraft.

The Lynx SAR operates in the Ku-Band anywhere within the range 15.2 GHz to 18.2 GHz, with 320 W of transmitter power. It is designed to operate and maintain performance specifications in adverse weather, using a Sandia derived weather model that includes 4 mm/hr rainfall. It forms fine-resolution images in real-time and outputs both NTSC video as well as digital images. The Lynx SAR has four primary operating modes. These are described as follows.

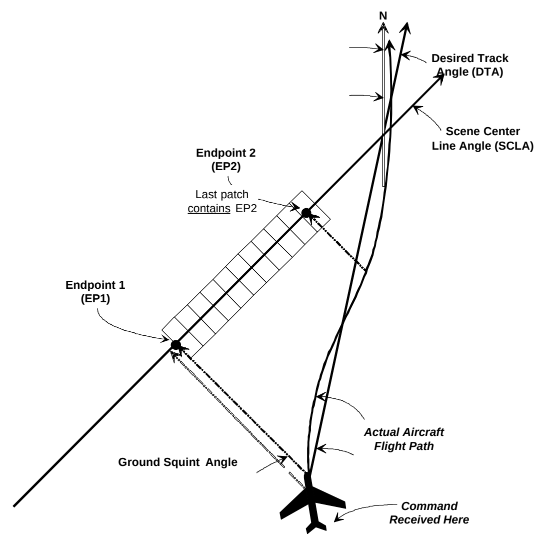

Figure 2. Geo-Referenced Stripmap Mode

SAR Geo-Referenced Stripmap Mode

In Geo-ref Mode, the operator specifies a precise strip on the ground to be imaged. The SAR then patches together a continuous and seamless string of images to yield the strip until the specified end-point is reached or the radar is commanded to do otherwise. The aircraft is not constrained to fly parallel to the strip, and images can be formed on either side of the aircraft. Specifications for this mode are given in Table 1.

Resolution	0.3 to 3.0	m	Both slant range and azimuth
Range	7 to 30	km	Slant range (3-60 km at reduced performance)
Ground swath	2600	pixels	Only with 16-node system (to 3500 pixels at coarser resolutions)
View size	934	m	At 0.3 m resolution, 45 deg. depression
Squint angle	+/– (45 to 135)	deg	Squint is difference between scene center-line and aircraft velocity vector

Table 1. Stripmap SAR Mode specifications.

SAR Transit Stripmap Mode

In Transit Mode, the operator specifies a range from the aircraft to the target line and the SAR forms a Stripmap parallel to the aircraft's flight path. The SAR then patches together a continuous and seamless string of images to yield the strip, and will continue to do so until commanded otherwise, or until the vehicle deviates too far from the original flight path. In the event of such a deviation, a new Transit Stripmap will begin immediately.

In all other respects, the performance of Transit Mode Stripmap is identical to Geo-ref Stripmap Mode.

SAR Spotlight Mode

In Spotlight Mode, the operator specifies the coordinates of a point on the ground and the SAR dwells on that point until commanded otherwise, or until the imaging geometry is exceeded. As with Stripmap modes, imaging may be on either side of the aircraft.

This mode allows finer resolutions than the Stripmap modes. Performance is summarized in Table 2.

In addition, an auto-zooming feature is also supported, where subsequent images are formed at ever finer resolutions until the SAR's limits are reached, or commanded to do otherwise.

Ground Moving Target Indication – GMTI

The relatively slow velocities of UAVs allow fairly simple exo-clutter GMTI schemes to offer reasonably good performance. The Lynx GMTI mode allows scanning over 270 degrees with performance summarized in Table 3.

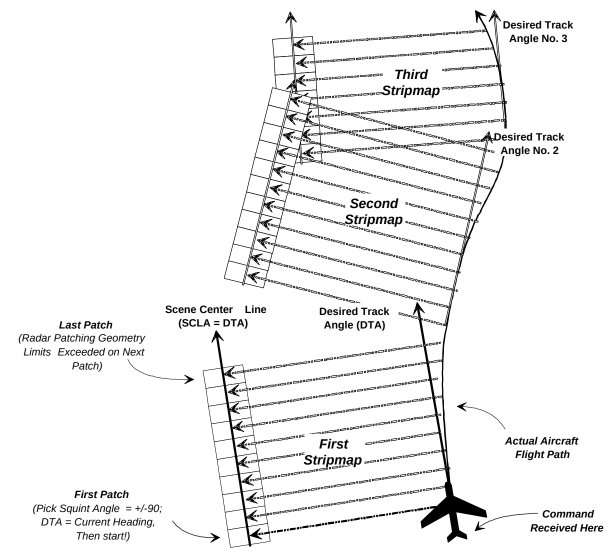

Figure 3. Transit Stripmap Mode

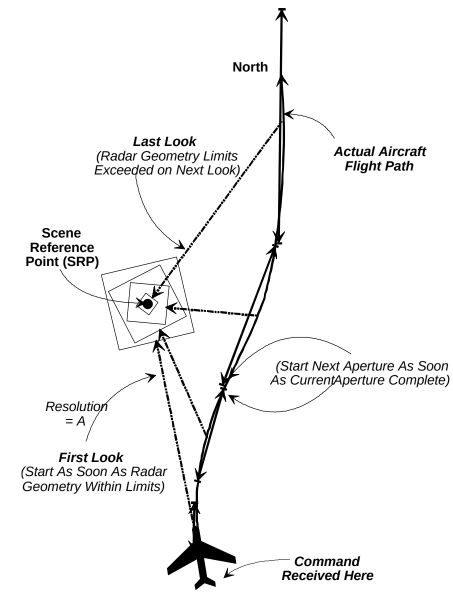

Figure 4. Spotlight SAR

Resolution	0.1 to 3.0	m	Select one of five
Range	4 to 25	km	Slant range (3-60 km at reduced performance)
Patch Size	2 x (640 x 480)	pixels	
View size	640 x 480	pixels	Over NTSC video link
Squint angle	+/– (50 to 130)	deg	
	+/– (45 to 135)	deg	0.15 m resolution and coarser

Table 2. Spotlight SAR Mode specifications.

Min. Detectable Velocity	5.8	kts	At 35 m/s (near range)
Range	4 to 25	km	Slant range
Angular Coverage	–135 to +135	deg	Total possible swept angle
Ground swath	10	km	Less at nearer ranges
Min. detectable target	+10	dBsm	
Max. Clutter	–10	dBsm/m^2	Average distributed clutter

Table 3. GMTI Mode specifications.

Figure 5. UAV Ground Station

Coherent Change Detection – CCD

Coherent Change Detection is a technique whereby two SAR images of the same scene are interfered. Any changes in the complex reflectivity function of the scene are manifested as a decorrelation in the phase of the appropriate pixels between the two images. In this manner, even very subtle changes in the scene from one image to the next can be detected. Necessarily, the images themselves must remain complex for this to work.[3]

In the SAR modes, the radar can output complex (un-detected) images that are necessary for Coherent Change Detection to work. These images can be transmitted to the ground station where ground-processing of the current image along with a library image allows near-real-time detection of changes in the scene. This operates with either Stripmap or Spotlight SAR images.

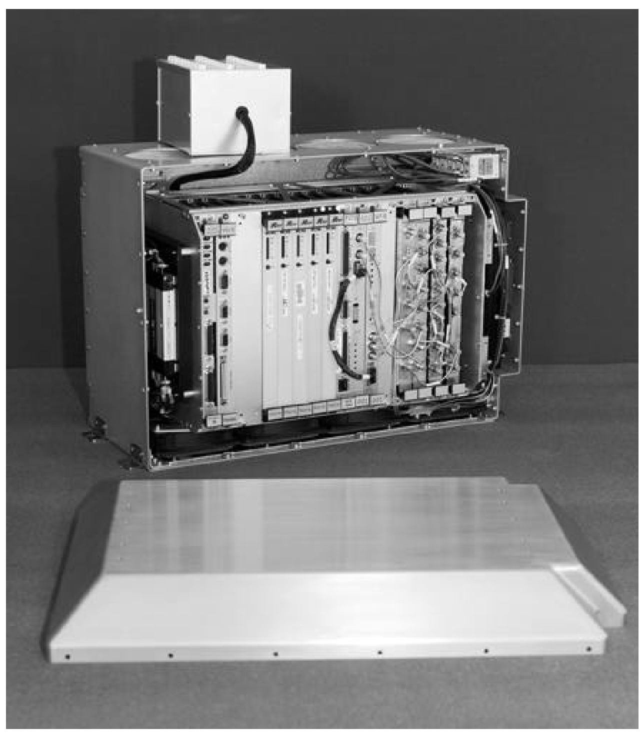

Figure 6. Lynx Radar Electronics Assembly

User Interface

Consistent with the philosophy for other sensors of the GA UAV family, the user interface for the SAR was designed to allow easy operation by an operator with minimal radar-specific knowledge. The operator selects resolution and operating mode, and then basically ‘points and shoots’ the radar, much like the optical sensors.

Radar images are transmitted to the radar operator by any of two means. The first is an NTSC video link which allows the SAR to be treated as “just another sensor” to a UAV payload operator. The radar actually forms larger images than can be displayed over the NTSC video link, but novel View Manager software allows the operator to pan and zoom within its memory. Images may be saved in on-board buffers for later viewing.

The second means of image transmission is a digital data link that can transmit an entire image at full resolution. This data can then be formatted to comply with the National Imagery Transmission Format, NITFS 2.0.

Target coordinates are easily extracted from any SAR image to facilitate pointing the SAR for new images. In GMTI mode, locations of detected movers are transmitted for display on map overlays.

3. HARDWARE

While SARs tend to be fairly complex instruments, a primary goal for Lynx was ease of manufacture. This drove all aspects of design.

The system has been designed as two relatively generic packages. These are the Radar Electronics Assembly (REA) and the Sensor Front-End or Gimbal Assembly. The combined weight is currently about 125 lb with some variance due to different cable assemblies for different platforms.

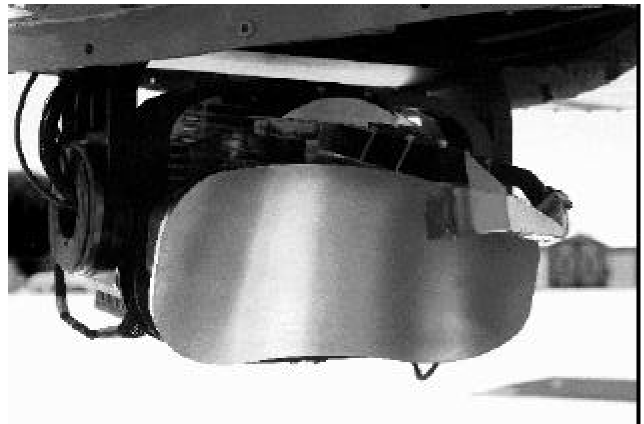

Figure 7. Lynx Gimbal Assembly

Radar Electronics Assembly – REA

The REA contains radar control, waveform generation, up-conversion, receiver, video, ADC, and signal processing functions. These functions exist in a custom VME chassis, with individual boards/assemblies roughly divided as follows.

The RF/Microwave functions are within a set of five VME boards/assemblies. These include the STALO module, Up-converter module, Ku-Band module, Receiver module, and the RF interconnect module. The only major RF/microwave functions not found in these modules are the transmitter TWTA and the receiver LNA.

Digital Waveform Synthesis (DWS) is accomplished by a custom VME board that generates a chirp with 42-bit parameter precision at 1 GHz. Although the board is custom, all components are off-the-shelf.

The Analog-to-Digital Conversion (ADC) is also accomplished by a custom VME board that operates at 125 MHz and provides 8-bit data. This data can be presummed and otherwise pre-processed before being sent across a RACEway bus to the signal processor.

The Signal Processor consists of 16 nodes of Mercury Computer Systems RACEway connected 200 MHz Power PCs. These implement a scalable architecture for image formation. Fewer nodes may be installed for a less capable SAR system. Four additional nodes are used for other radar functions including Motion Measurement, Radar Control, and optional data recording.

Gimbal Assembly

The Gimbal assembly contains antenna, motion measurement hardware, and front-end microwave components including the TWTA.

The gimbal itself is a 3-axis gimbal custom designed and built by Sandia specifically for the Lynx radar. All components are mounted on the inner gimbal.

The antenna was custom designed at Sandia specifically for the Lynx radar. It is a vertically polarized horn-fed dish antenna with a 3.2 degree azimuth beamwidth and a 7 degree elevation beamwidth.

Figure 8. Litton LN-200 IMU

Motion measurement is a Carrier-Phase-GPS-aided Inertial Navigation System centered around a Litton LN-200 Fiber Optic IMU. This is augmented by an Interstate Electronics Corporation GPS receiver.

The front-end microwave components include a TWTA capable of outputting 320 W at 35% duty factor averaged over the Lynx frequency band, and an LNA that allows an overall system noise figure of about 4.5 dB.

4. IMAGE FORMATION

Image formation in all SAR modes is accomplished by stretch processing[2], that is, de-ramping the received chirp prior to digitizing the signal. After the ADCs, presumming is employed to maximize SNR in the image and minimize the load on the subsequent processors. The algorithm used thereafter is an expanded version of the Sandia developed Overlapped-Subaperture (OSA) processing algorithm[1], followed by Sandia developed Phase-Gradient Autofocus (PGA)[3]. Either complex images or detected images can be exported to View Manager software.

5. MOTION MEASUREMENT/COMPENSATION

Motion measurements are received from an Inertial Measurement system mounted on the back of the antenna itself. These are augmented by carrier-phase GPS measurements and combined in a Kalman filter to accurately estimate position and velocity information crucial to proper motion compensation in the SAR. This processing is done on a single Power PC processing node.

The Motion Compensation philosophy for this radar is to perform compensation as early as possible in the signal path. Transmitted waveform parameters are adjusted, as well as pulse timing, to collect optimal data on the desired space-frequency grid. This is prior to digital sampling, and minimizes the need for subsequent data interpolation.[4] During image formation, residual spatially variant phase errors are compensated as spatial coordinates become available during OSA processing. Finally, any errors due to unsensed motion are mitigated by an autofocus operation.

6. FLIGHT TESTS

Flight tests began in July 1998 with the radar mounted in Sandia's DOE Twin-Otter manned aircraft, and continued through February 1999. The first flights in a GA Aeronautical Systems, Inc. I-GNAT UAV occurred in March 1999. To date, two Lynx SARs have been built by Sandia. GA is currently constructing a third unit, and will build all subsequent units.

Figure 9. Sandia National Laboratories DOE DeHavilland DH-6 Twin-Otter

The SAR currently meets its image quality goals and routinely makes high-quality fine-resolution images. The first CCD images have been processed at the time of this writing. For GMTI mode, data has been collected and is undergoing analysis to adjust the processing for optimal performance.

7. SUMMARY

We have described Lynx - a lightweight, high performance SAR. Lynx operates in Ku band and features spotlight and stripmap SAR modes, a GMTI mode, and CCD. In spotlight mode it is capable of 0.1 m resolution, while in stripmap mode it is capable of 0.3 m resolution. At the finest resolution in weather, Lynx has a slant range of 25 km, but at coarser resolution can be operated up to 45 km. It is designed be operated on a variety of manned and unmanned platforms. All the image processing is done in the air and the imagery (real or complex) is downlinked from an unmanned platform. Phase histories and/or imagery may be recorded in a manned platform. No post-processing of the imagery is required (except CCD). The Lynx production weight is less than 120 lb. Lynx also features a user friendly mode of operation that allows the SAR to be used like a video camera.

At the time of this writing all SAR image specifications have been met or exceeded in manned flight tests. Integration into the GA I-GNAT is proceeding, and the first unmanned flight tests are about to begin.

8. ACKNOWLEDGMENTS

Many other individuals, both at Sandia and at GA, provided crucial efforts towards making the Lynx SAR a reality. This was truly a team effort. The authors wish to acknowledge them and thank them. It is a real pleasure to work with good people.

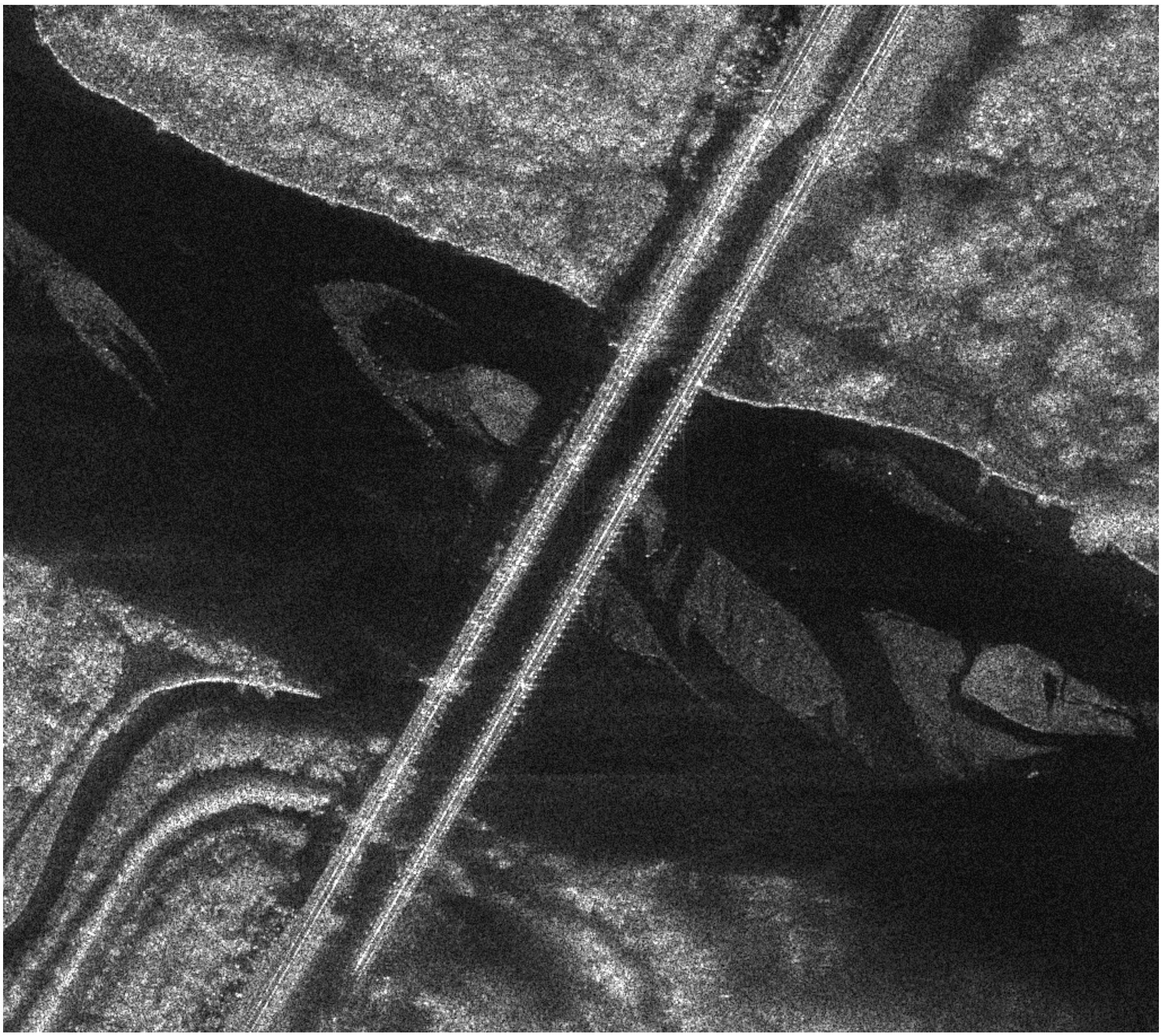

Figure 10. Belen railroad bridge over Rio Grande river (1 ft resolution Spotlight Mode)[5].

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9. REFERENCES

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5. High quality 4" resolution imagery can also be made routinely.

Figure 11. Albuquerque Atomic Museum, KAFB (1 ft resolution Spotlight Mode)[5].